FIG. 1

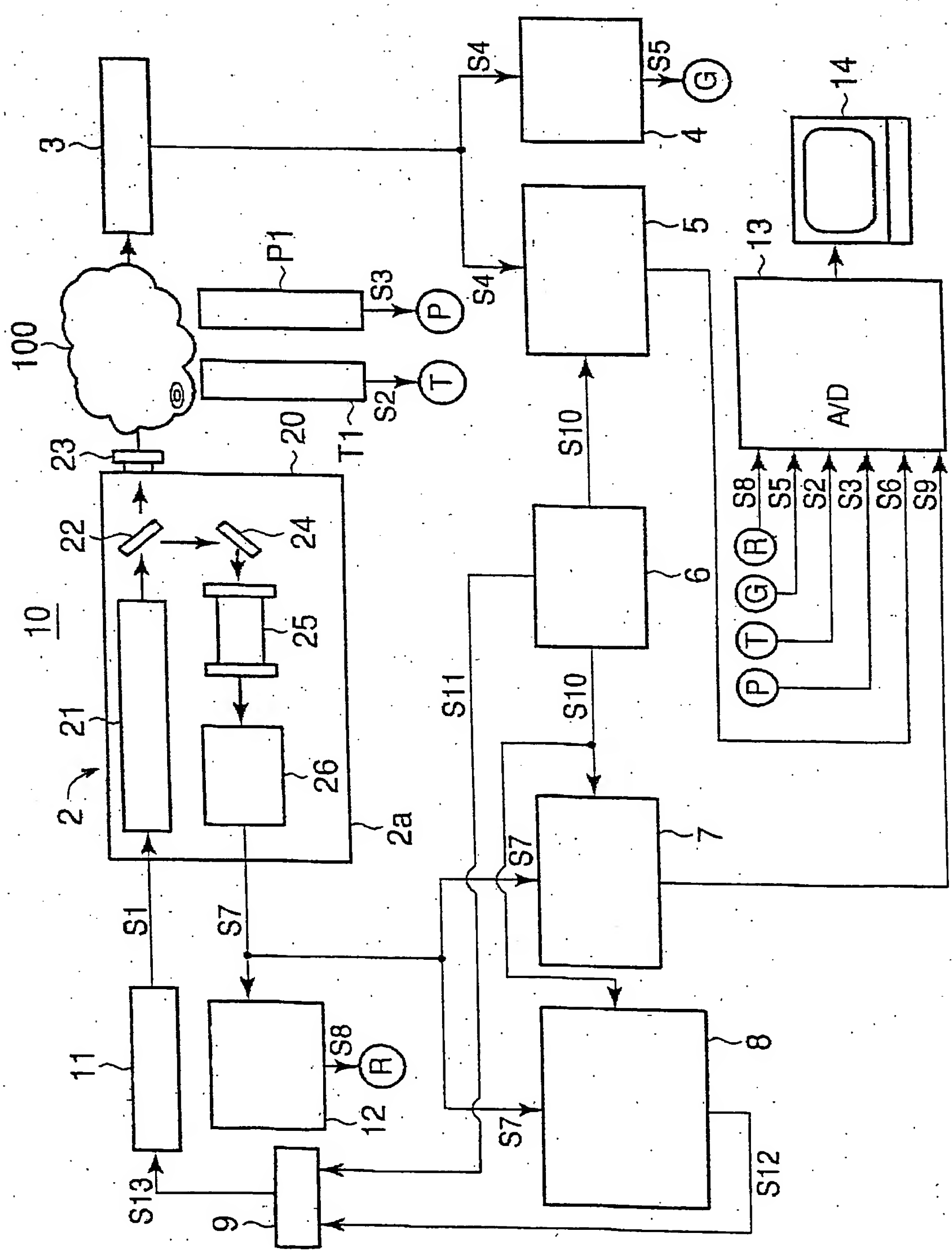
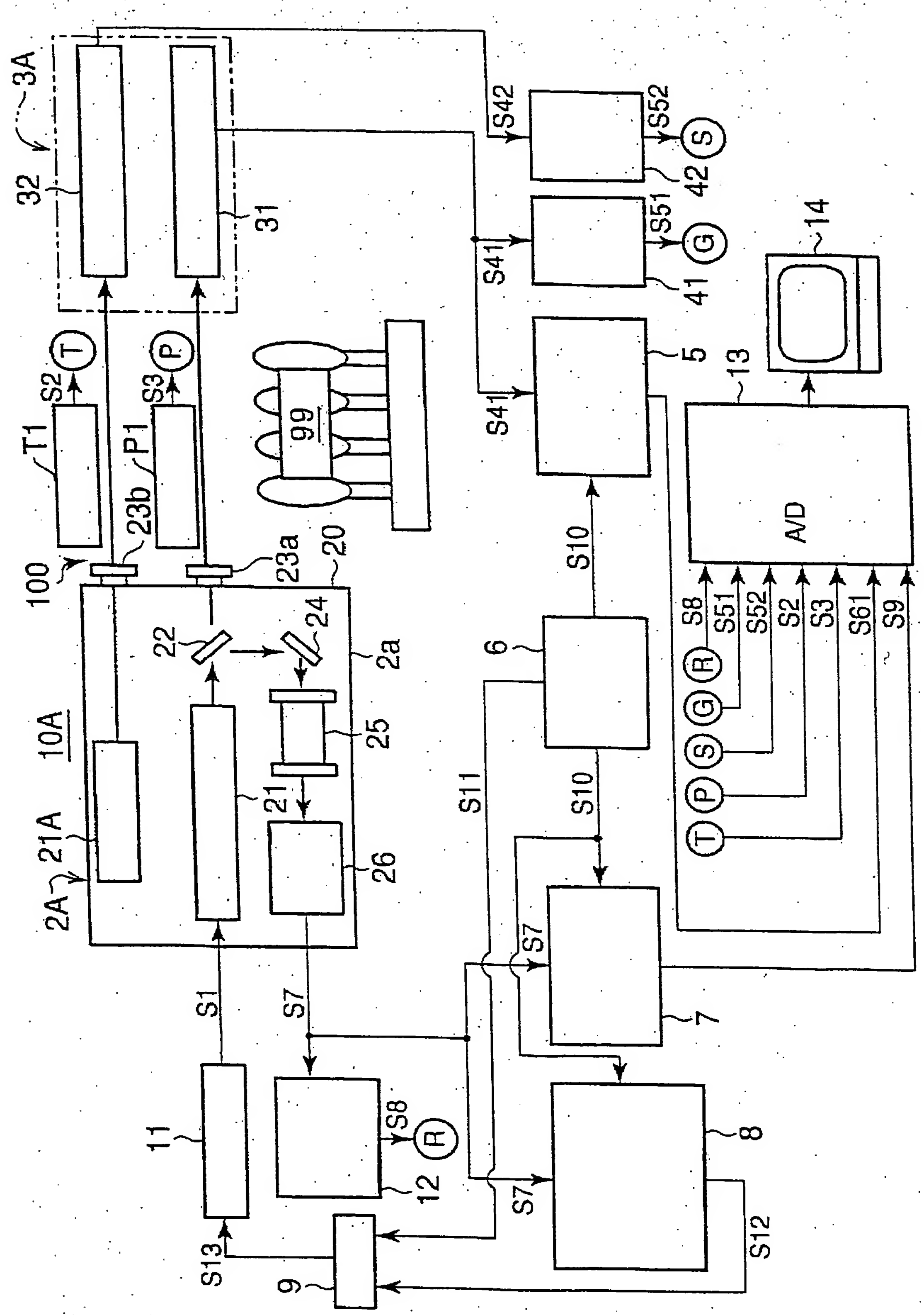
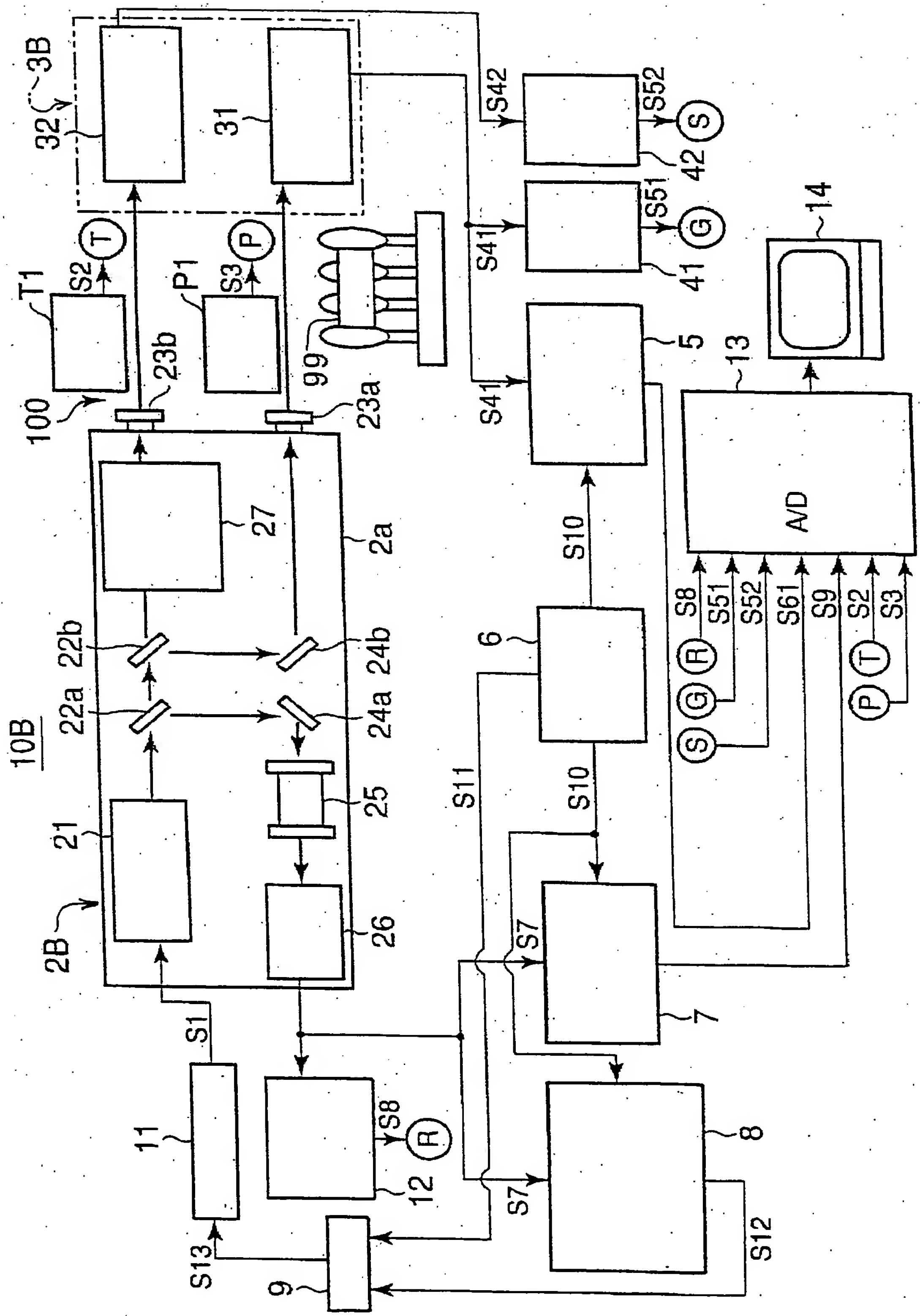


FIG. 2



3A
32
31
T1
P1
S2
S3
T
P
100
23b
23a
20
99
S42
S52
S
42
S51
G
41
S41
5
14
13
A/D
S10
6
S8
S51
S52
S2
S3
S61
S9
R
22
24
2a
10A
25
21
21A
2A
26
S11
S7
7
S1
11
12
8
9
S13
S12

FIG. 3



10B
2B
21
22a
22b
24a
24b
25
26
27
2a
23a
23b
100
T1
S2
T
P1
S3
P
99
3B
32
31
S42
S52
S
42
S41
S51
G
41
5
14
13
A/D
S8
S51
S52
S61
S9
S2
S3
R
G
S
T
P
6
S10
S11
7
S7
8
S12
9
S13
11
S1
12

FIG. 4

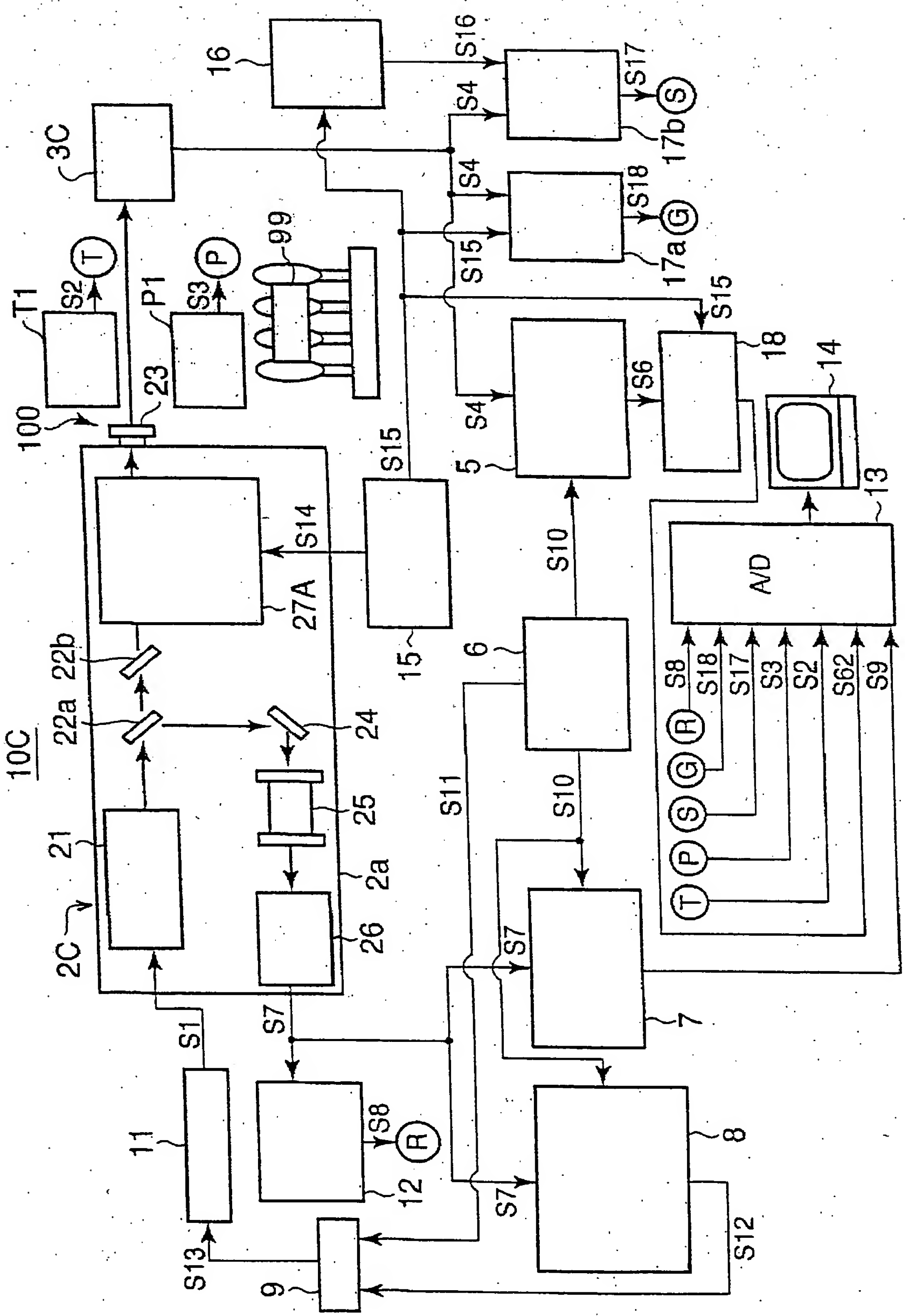
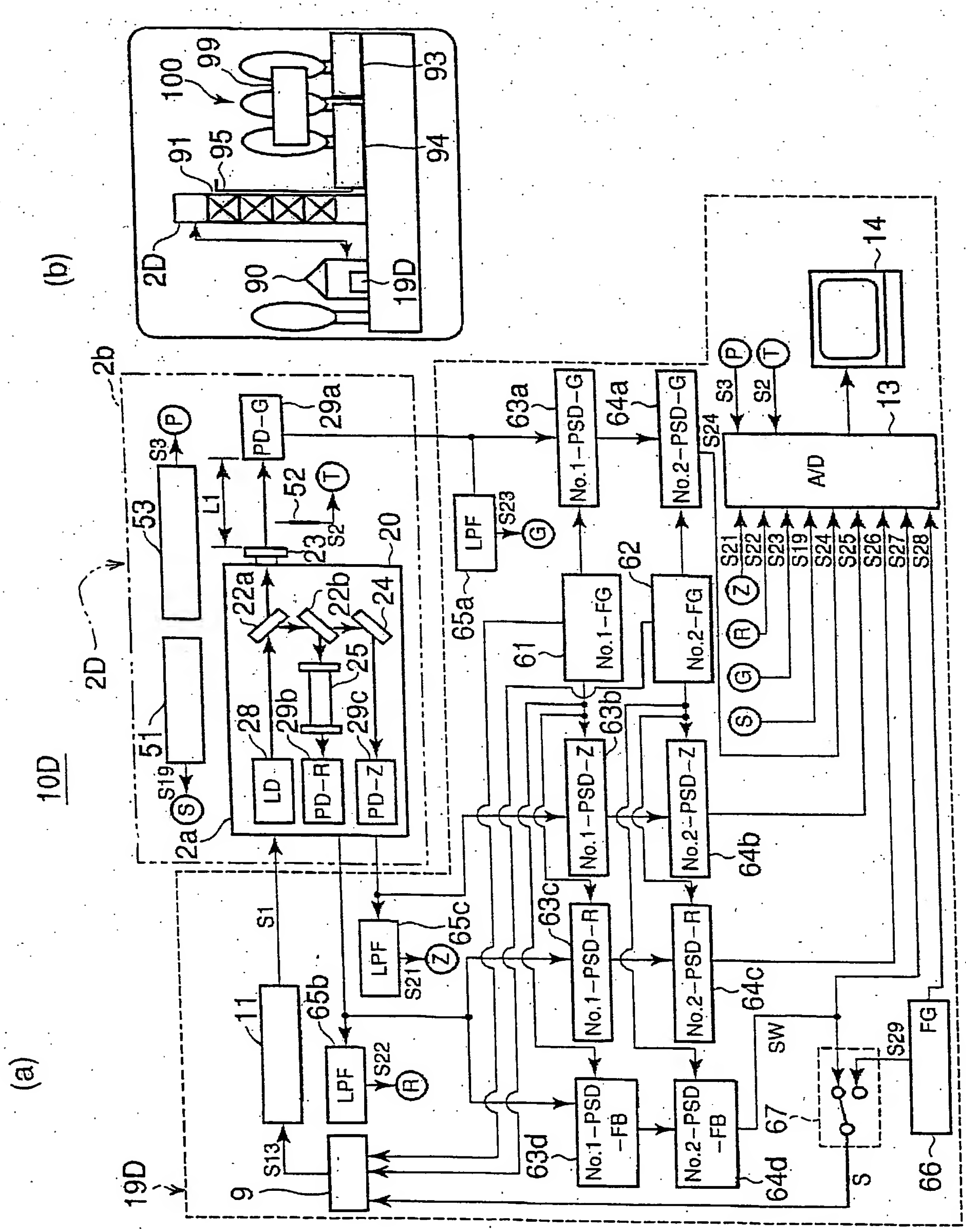

10C
2C
2a
21
22a
22b
23
24
25
26
27A
100
T1
P1
99
3C
16
17a
17b
18
5
6
7
8
9
11
12
13
14
15
A/D
S1
S2
S3
S4
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16
S17
S18
S62
T
P
S
G
R

FIG. 5



(a)
(b)
10D
2D
2a
2b
19D
LD
PD-R
PD-Z
PD-G
LPF
A/D
FG
SW
No.1-FG
No.2-FG
No.1-PSD-G
No.2-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD-FB
No.2-PSD-FB
L1
S1
S2
S3
S13
S19
S21
S22
S23
S24
S25
S26
S27
S28
S29
S
P
T
G
R
Z
9
11
13
14
20
22a
22b
23
24
25
28
29a
29b
29c
51
52
53
61
62
63a
63b
63c
63d
64a
64b
64c
64d
65a
65b
65c
66
67
90
91
93
94
95
99
100

FIG. 6

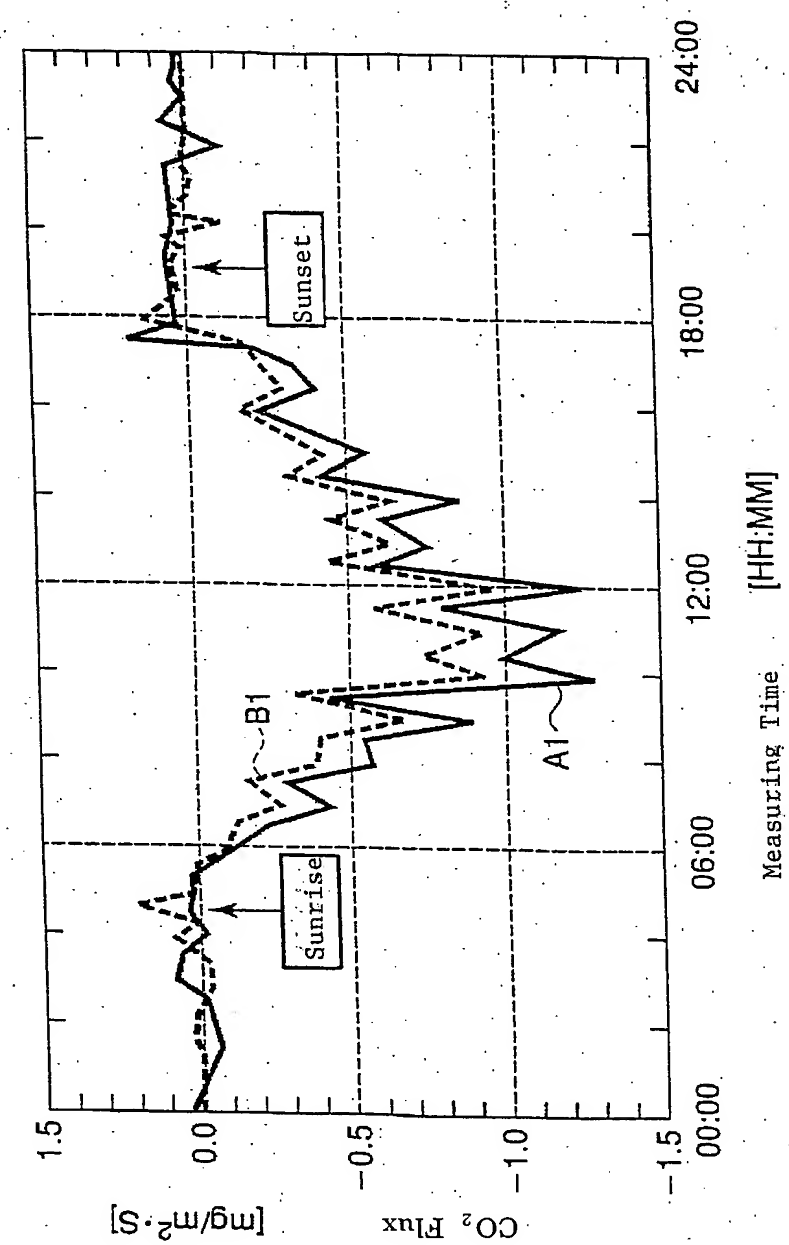
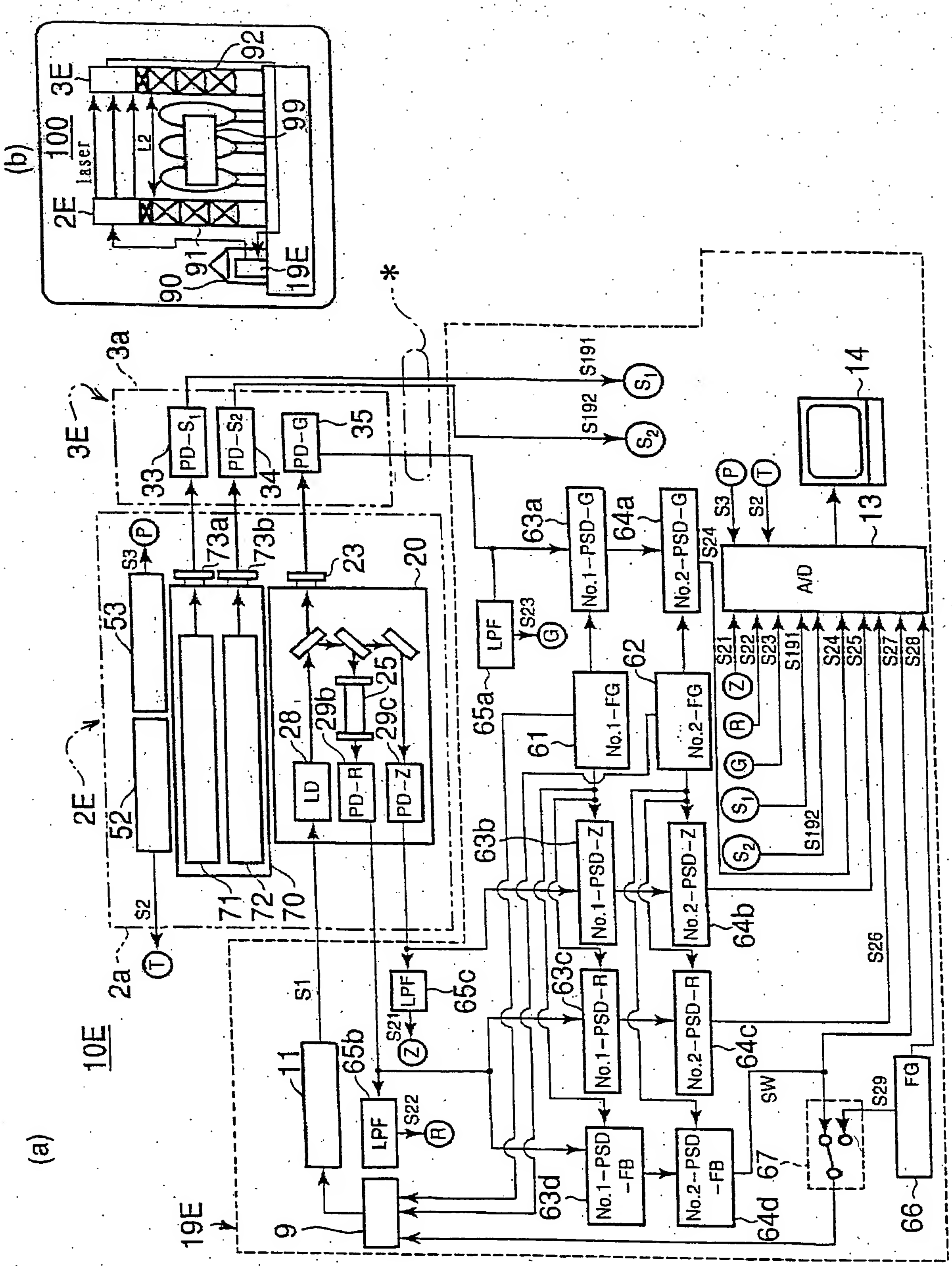
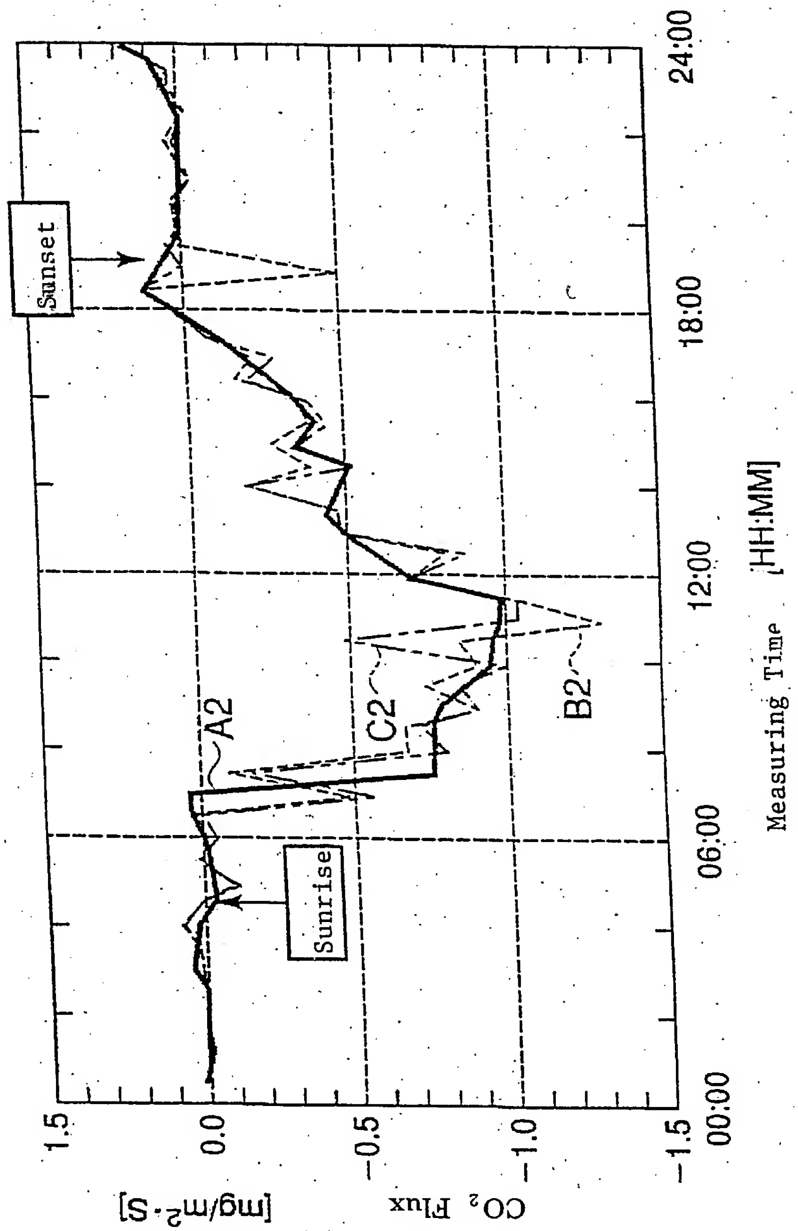

Sunrise
Sunset
A1
B1
1.5
0.0
−0.5
−1.0
−1.5
CO_2 Flux
[mg/m²·S]
00:00
06:00
12:00
18:00
24:00
Measuring Time
[HH:MM]

FIG. 7



(a)
(b)
10E
2E
3E
2a
3a
19E
100
laser
L2
90
91
92
99
PD-S1
PD-S2
PD-G
LD
PD-R
PD-Z
LPF
A/D
FG
SW
No.1-FG
No.2-FG
No.1-PSD-G
No.2-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD-FB
No.2-PSD-FB
S1
S2
S3
S21
S22
S23
S24
S25
S26
S27
S28
S29
S191
S192
9
11
13
14
20
23
25
28
29b
29c
33
34
35
52
53
61
62
63a
63b
63c
63d
64a
64b
64c
64d
65a
65b
65c
66
67
70
71
72
73a
73b

FIG. 8



Sunset
Sunrise
A2
C2
B2
1.5
0.0
-0.5
-1.0
-1.5
CO2 Flux [mg/m2·S]
00:00
06:00
12:00
18:00
24:00
Measuring Time [HH:MM]

FIG. 9

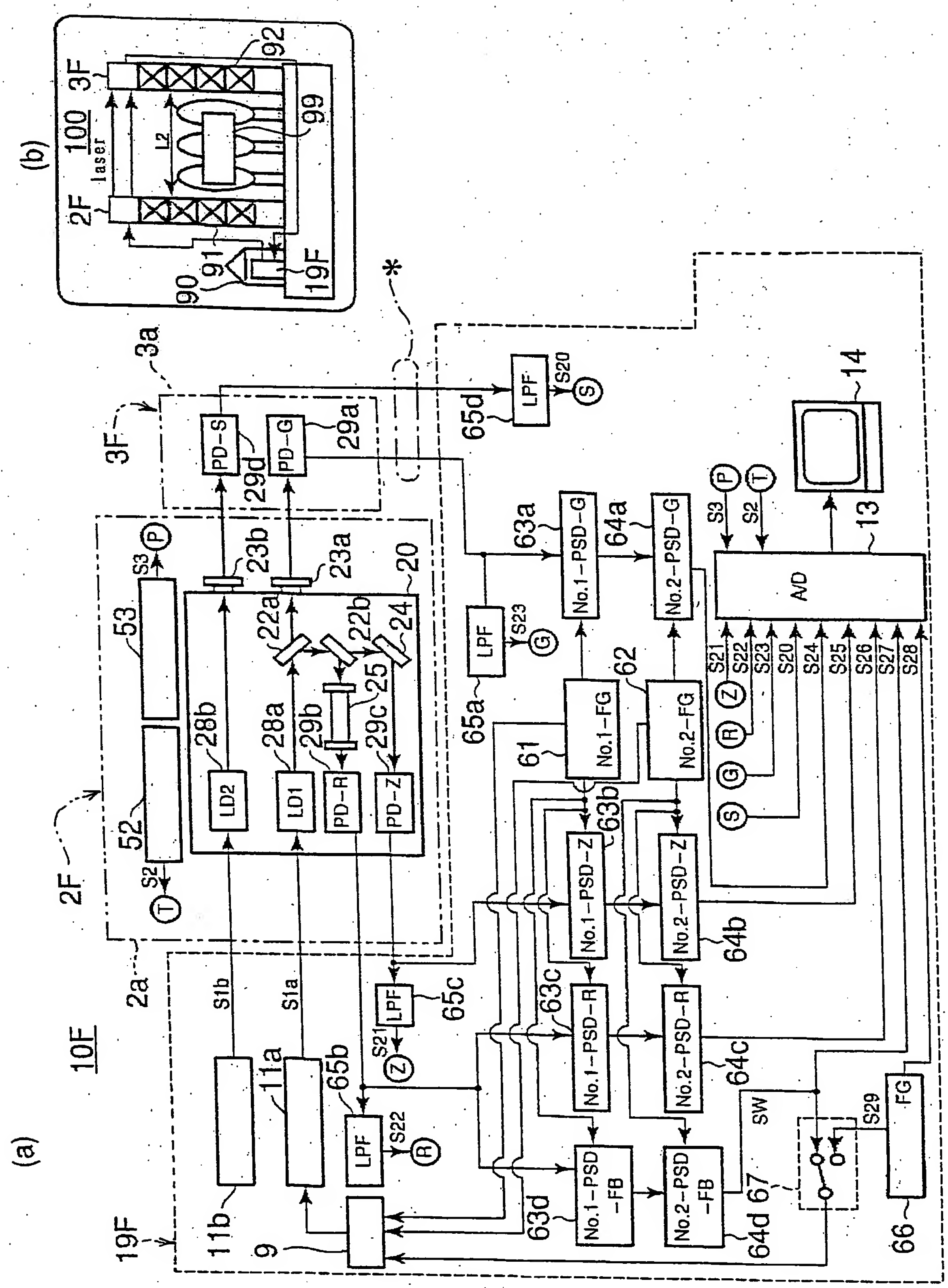
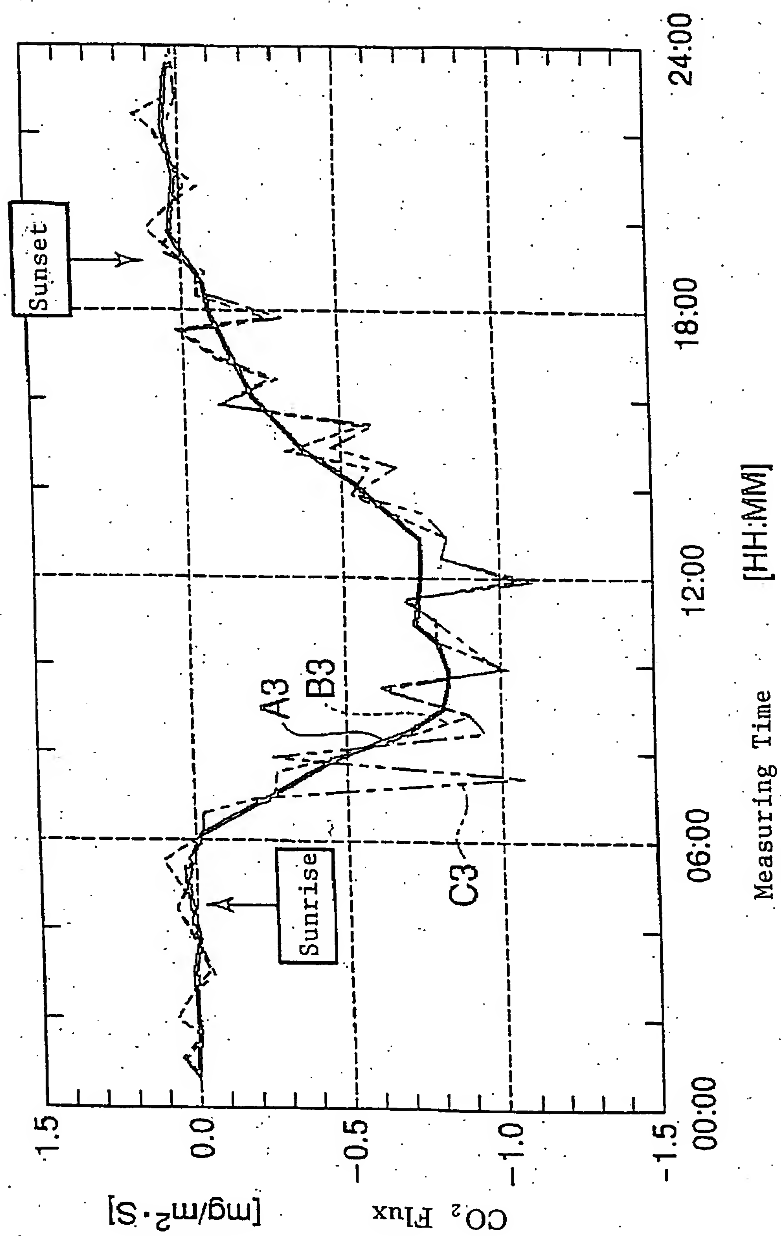
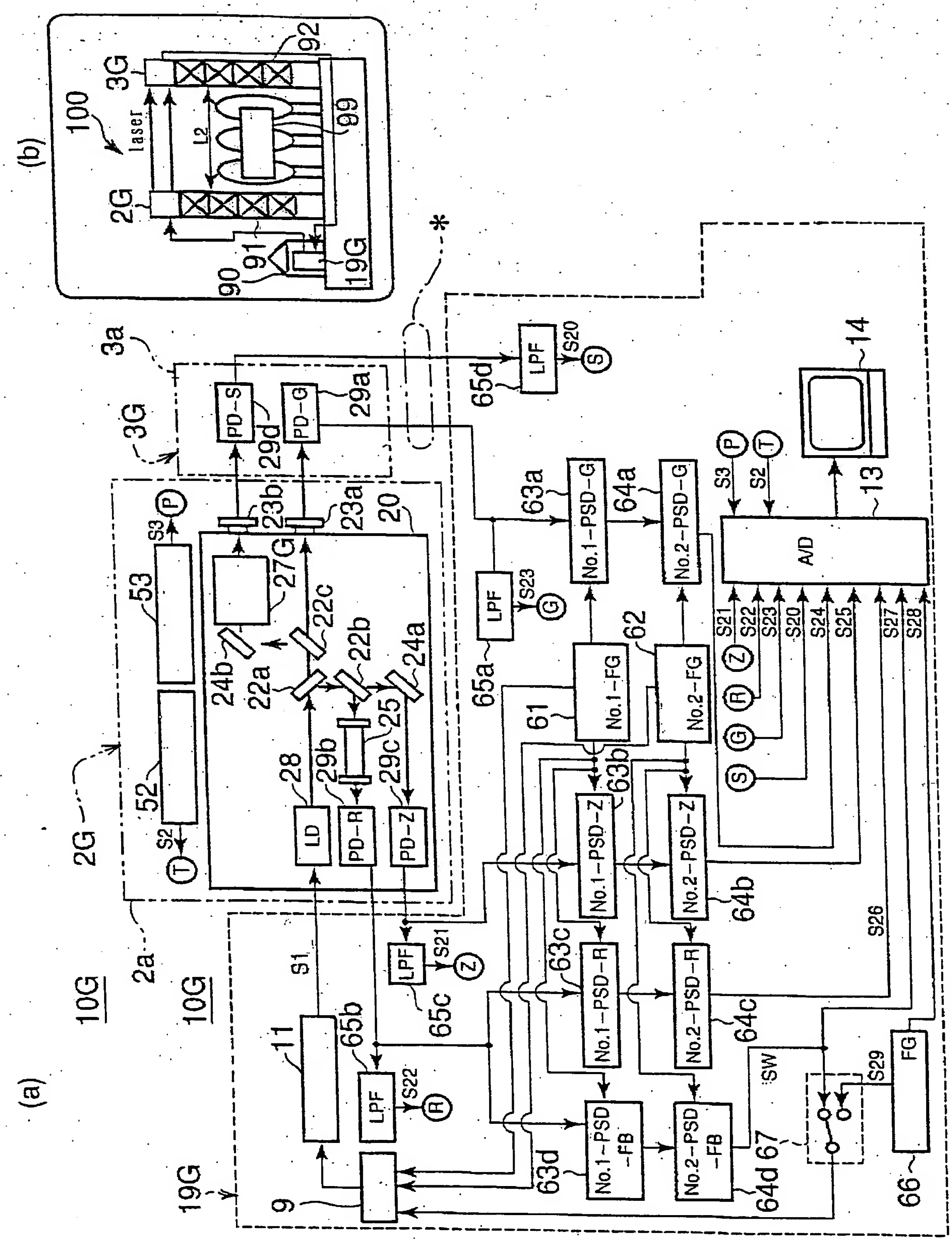

(a)
(b)
10F
2F
3F
19F
2a
3a
100
laser
L2
LD1
LD2
PD-R
PD-Z
PD-S
PD-G
LPF
No.1-FG
No.2-FG
No.1-PSD-G
No.2-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD -FB
No.2-PSD -FB
A/D
FG
SW
S1a
S1b
S2
S3
S20
S21
S22
S23
S24
S25
S26
S27
S28
S29
*

FIG. 10



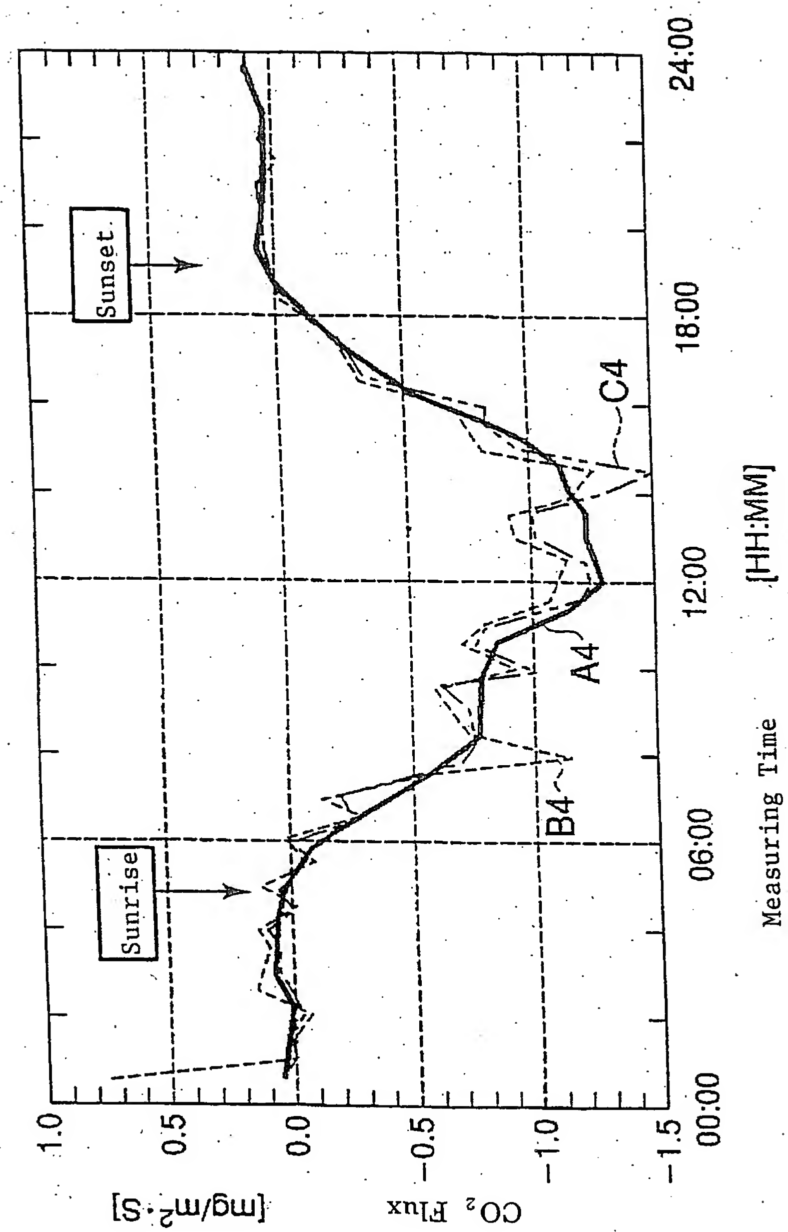
Sunset
Sunrise
A3
B3
C3
1.5
0.0
-0.5
-1.0
-1.5
00:00
06:00
12:00
18:00
24:00
CO_2 Flux
[mg/m²·S]
Measuring Time
[HH:MM]

FIG. 11



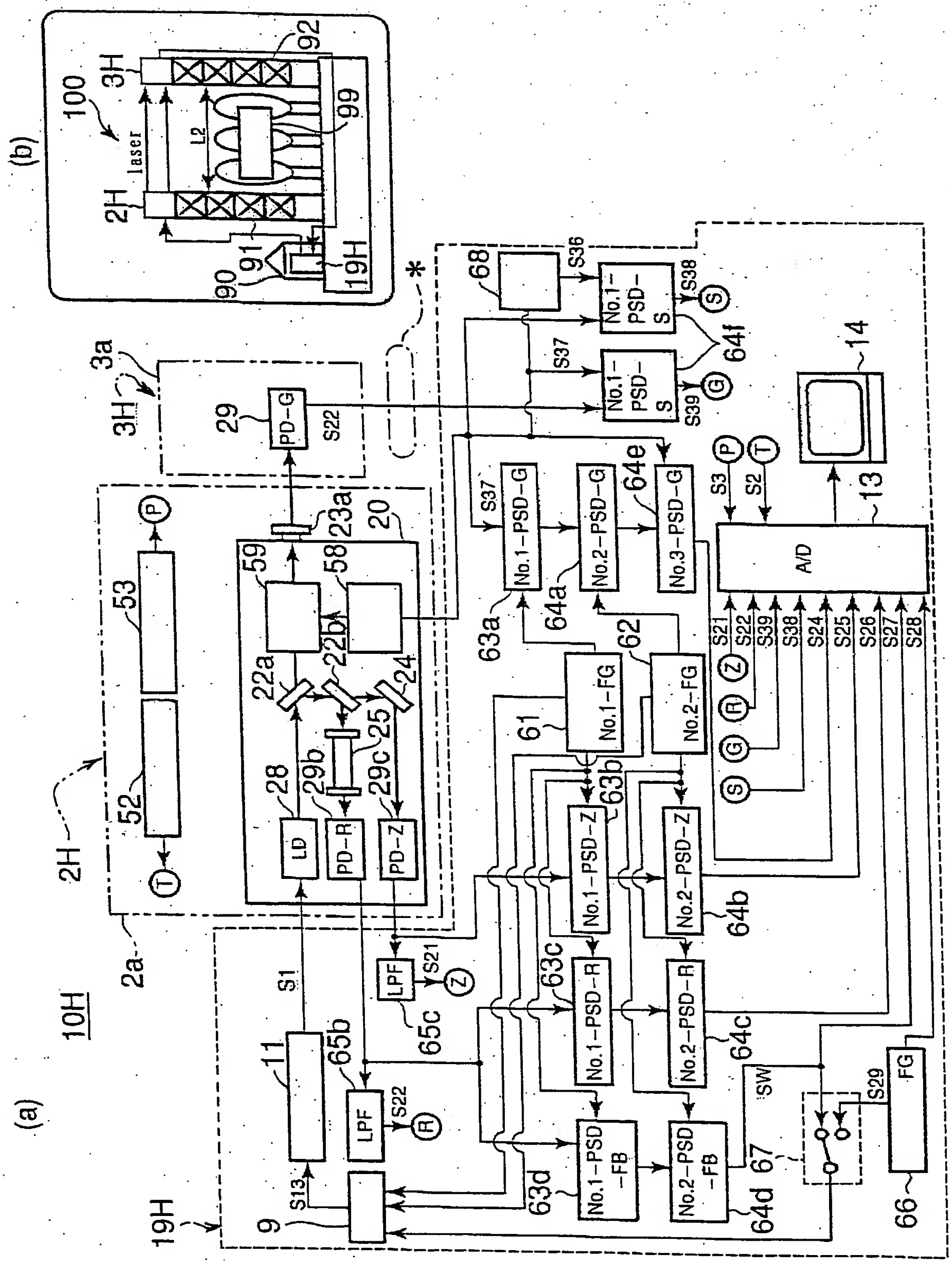
(a)
(b)
100
laser
L2
2G
3G
90
91
92
99
19G
10G
2a
3a
LD
PD-R
PD-Z
PD-S
PD-G
LPF
A/D
No.1-FG
No.2-FG
No.1-PSD-G
No.2-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD-FB
No.2-PSD-FB
FG
SW
S1
S2
S3
S20
S21
S22
S23
S24
S25
S26
S27
S28
S29

FIG. 12



CO$_2$ Flux [mg/m^2·S]
1.0
0.5
0.0
-0.5
-1.0
-1.5
00:00
06:00
12:00
18:00
24:00
Measuring Time [HH:MM]
Sunrise
Sunset
A4
B4
C4

FIG. 13



(a)
(b)
10H
100
laser
L2
2H
3H
19H
90
91
92
99
2a
3a
20
11
9
13
14
LD
PD-R
PD-Z
PD-G
LPF
A/D
FG
SW
No.1-FG
No.2-FG
No.1-PSD-G
No.2-PSD-G
No.3-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD-FB
No.2-PSD-FB
No.1-PSD-S
52
53
58
59
22a
22b
24
25
28
29
29b
29c
23a
61
62
63a
63b
63c
63d
64a
64b
64c
64d
64e
64f
65b
65c
66
67
68
S1
S2
S3
S13
S21
S22
S24
S25
S26
S27
S28
S29
S36
S37
S38
S39
T
P
Z
R
G
S
*

FIG. 14

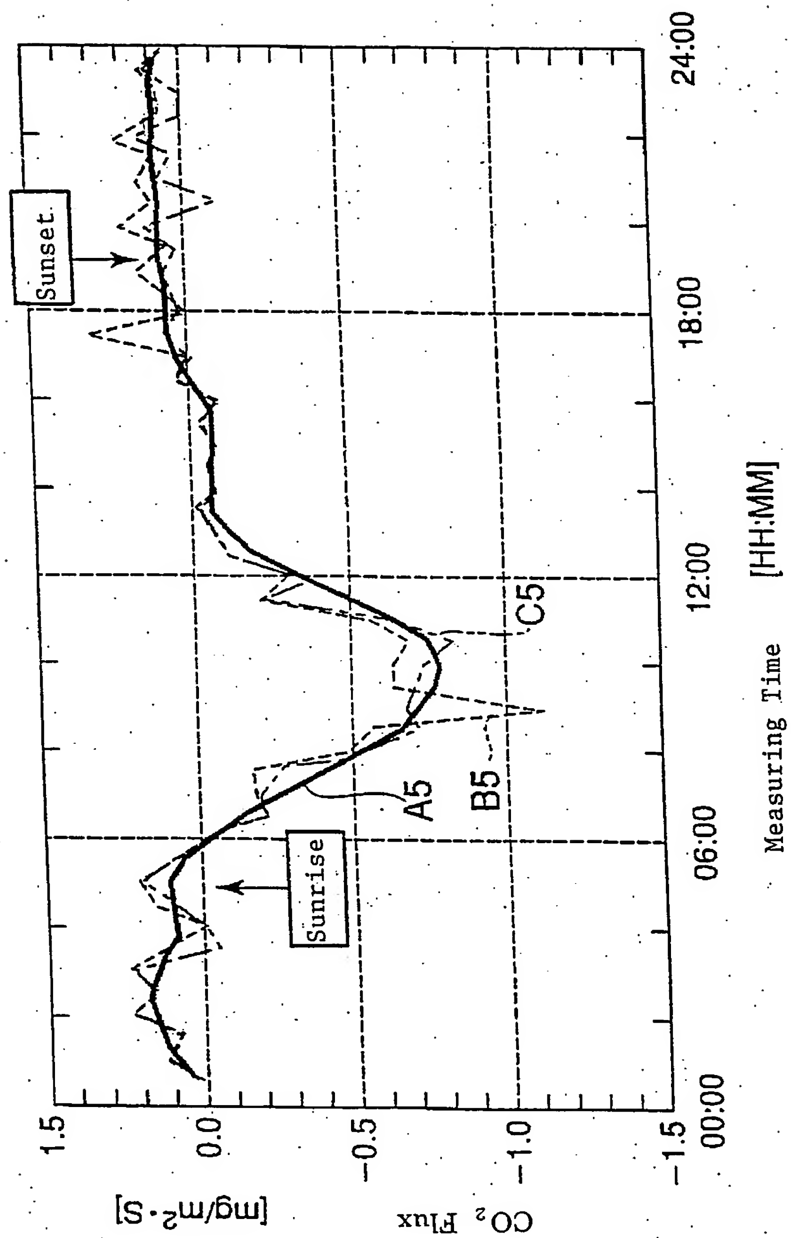

Sunset
Sunrise
A5
B5
C5
1.5
0.0
−0.5
−1.0
−1.5
00:00
06:00
12:00
18:00
24:00
Measuring Time
[HH:MM]
CO_2 Flux
[mg/m²·S]

FIG. 15A (Prior Art)

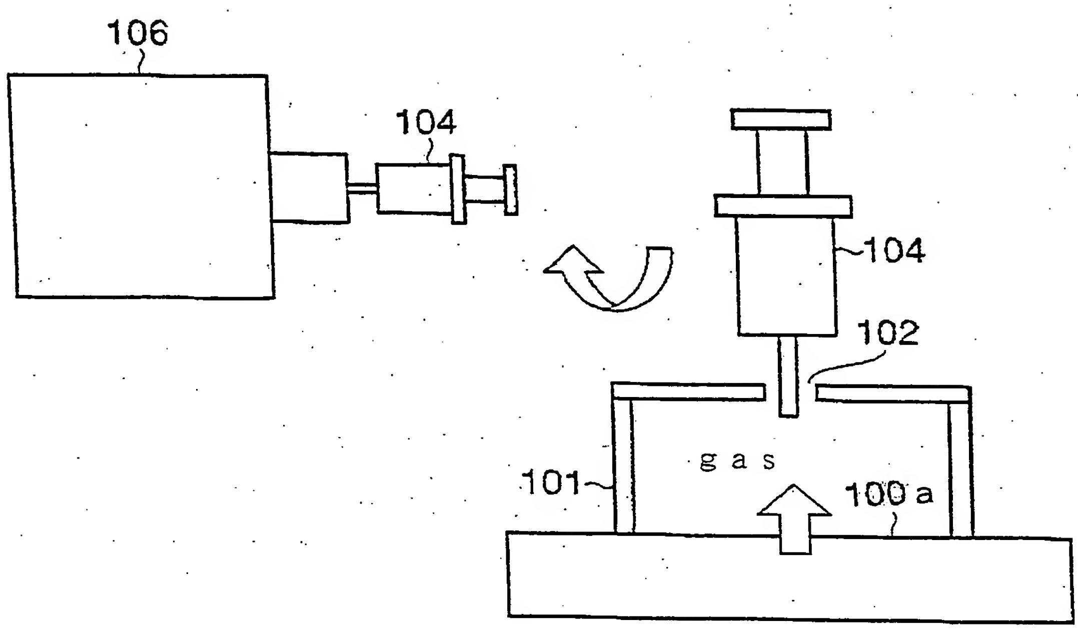


FIG. 15B (Prior Art)

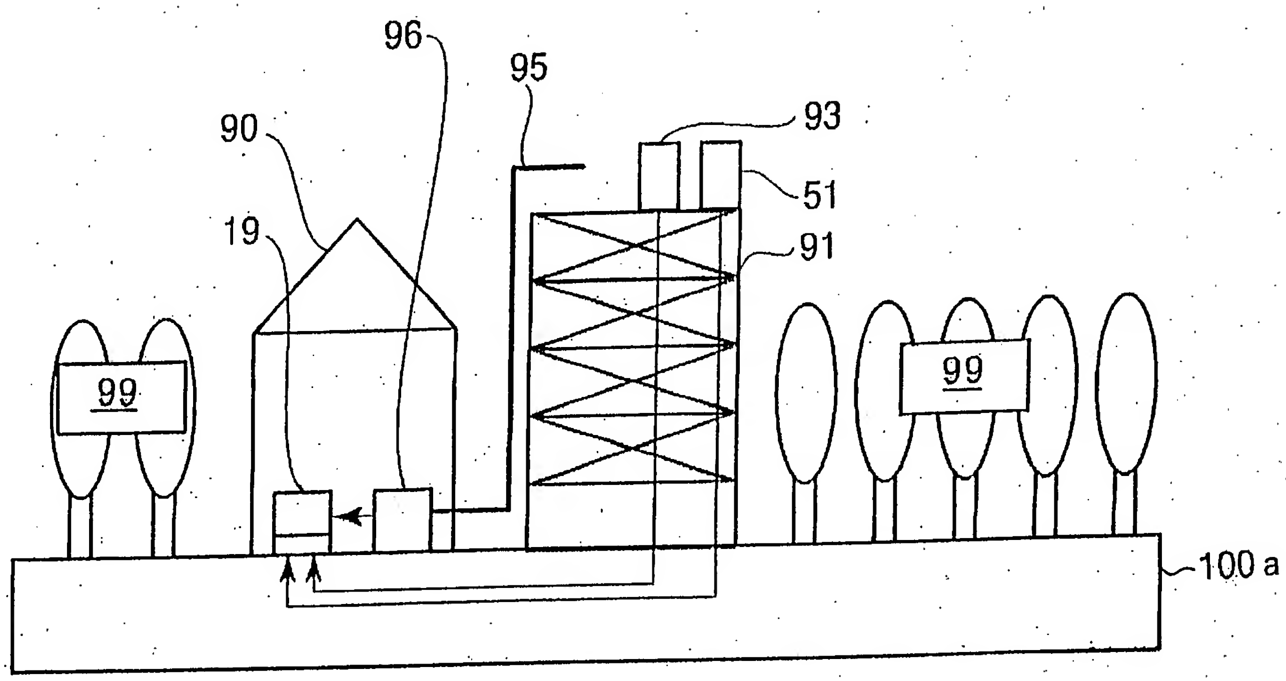


FIG. 15C (Prior Art)

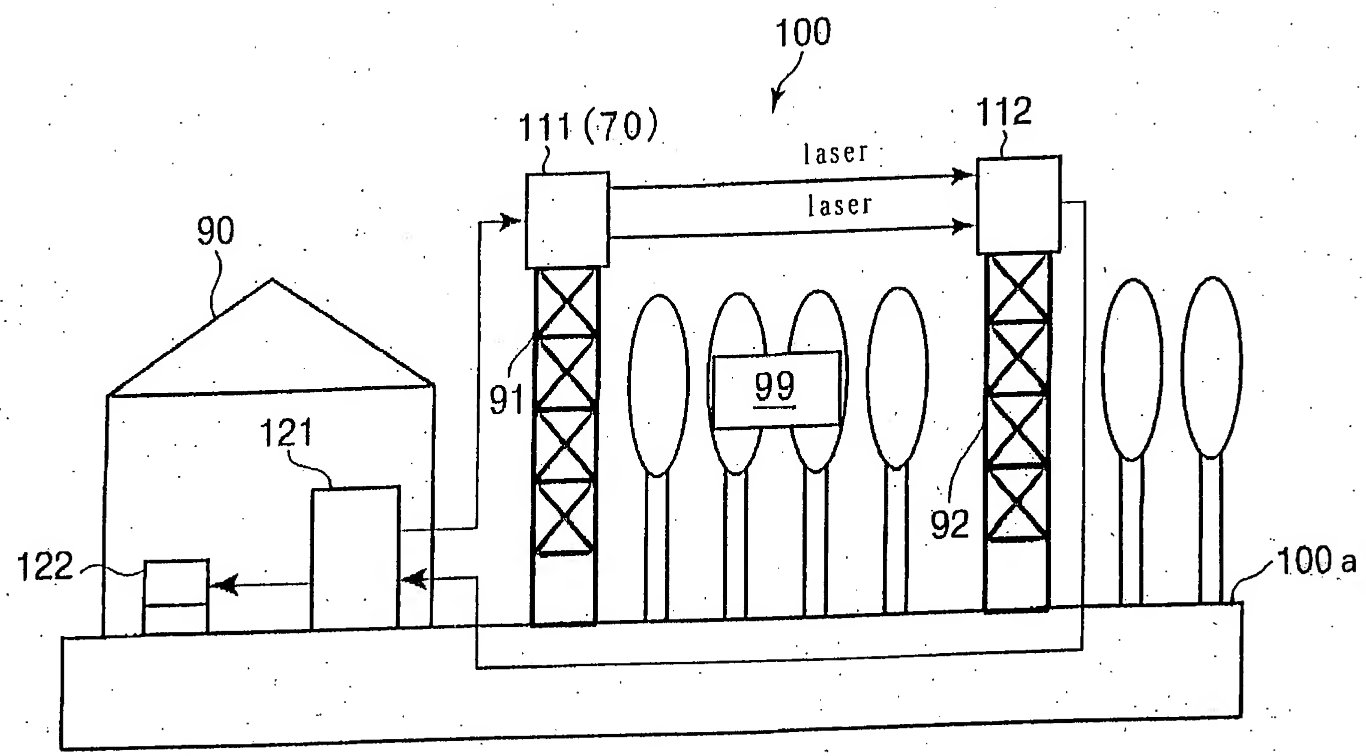


FIG. 15D (Prior Art)

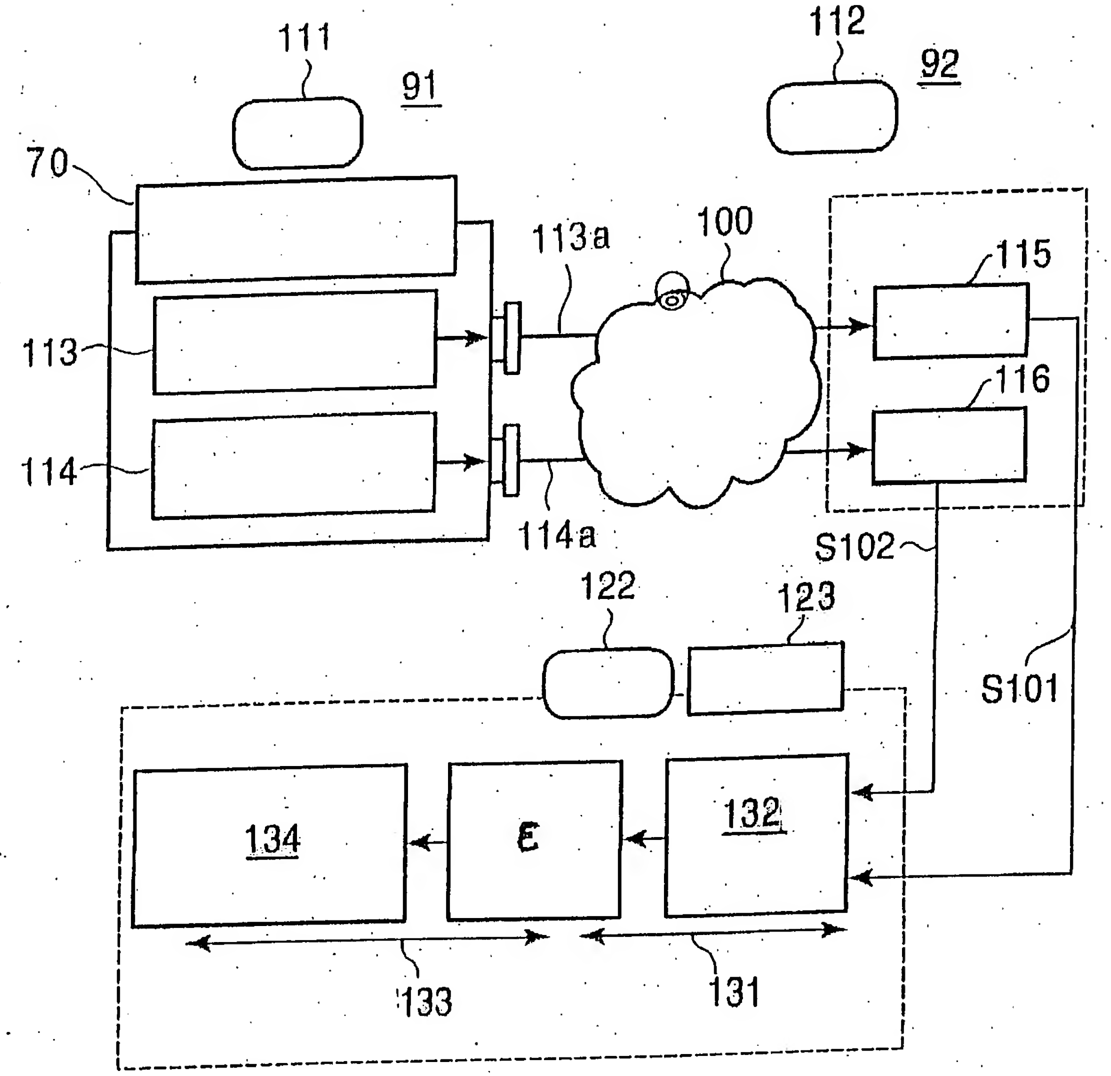


Fig. 16A

Raw data of atmospheric turbulence measurements (observation of atmospheric transmission factor of laser)

Time-wise changes of atmospheric transmission factor of 2 optical path lasers

- B1, B2: Logarithmic variance of laser strength
- B12: Logarithmic covariance of laser strength
- r: Logarithmic correlation coefficient of laser strength

↓

Grasping of atmospheric turbulence state (optical spectrum analysis of atmospheric turbulence state)

Obtaining of internal scale Lo and structure function constant Cn^2 of refractive index changes

In case of different laser wavelengths:

$r=F(Lo, \lambda 1, \lambda 2)$

$B12=aCn^2G(Lo, \lambda 1, \lambda 2)$

λn: Laser wavelength, a: Constant

In case of the same laser wavelength:

$r=F(Lo)$

$B12=aCn^2G(Lo, d, D)$

d: Distance between laser radiating positions,

D: Diameter of light receiving part

Obtaining of structure function constant of temperature and water vapor changes

$CN^2=A_T^2/T^2C_T^2+A_q^2/q^2C_q^2+2A_TA_q/TqC_{Tq}$

$C_{Tq}=(C_T^2C_q^2)^{1/2}$ A_T, A_q: Constant

Dissipation rate of variance of kinetic energy

$\varepsilon = \gamma^3(7.4/Lo)^4$

Dissipation rate of variance of temperature and humidity changes

$C_T^2=4\beta\,\varepsilon_T\,\varepsilon^{-1/3}$ β: Obkhov-Corsin Constant $C_q^2=4\beta\,\varepsilon_q\,\varepsilon^{-1/3}$

↓

Obtaining of momentum flux and scalar flux (analysis based on the MOS law)

Fig. 16B

The followings are obtained by repeated calculations based on the MOS law.

(1)	MO length	$z/L = kgz(H/Cp\ Ta + 0.61E)/[-u*3\rho]$
(2)	Friction velocity	$u* = [kz\ \varepsilon\ /(\phi_{\varepsilon}(z/L)]^{1/3}$
(3)	Sensible heat flux	$H = \rho Cp[kzu*\ \varepsilon_{T}/\ \phi_{\varepsilon T}(z/L)]^{1/2}$
(4)	Latent heat flux	$LE = \rho L[kzu*\ \varepsilon_{q}/\ \phi_{\varepsilon q}(z/L)]^{1/2}$

z : Measuring height, k : Karman Constant, g : Gravitational acceleration,

Cp : Constant pressure specific heat of air, ρ : Air density

$\phi n(z/L)$: Monin-Obukhov universal function ($n = \varepsilon, \varepsilon_{T1}\ \varepsilon q$)

Momentum Flux=$\rho\overline{u^{I}w^{I}}$

Sensible heat flux=$\rho cp\overline{T^{I}w^{I}}$

Water vapor flux=$\rho\overline{Lq^{I}w^{I}}$

Fig. 17A

1. Turbulence state measurements

Grasping of atmospheric turbulence state

(1) Scintillation measurements of laser

(2) Calculation of statistical quantity (variance, covariance) using measured values

Analysis of atmospheric turbulence state

(1) Calculation of internal scale Lo

(2) Lo→Turbulence energy dissipation rate ε

(3) Structure function parameter of density: Calculation of Cn^2

2. Atmospheric gas concentration measurements

Grasping of gas concentration

$$\text{Gas concentration} = \frac{\left(\frac{\text{Atmospheric side laser absorption quantity}}{\text{Atmospheric side laser received light strength}}\right)}{\left(\frac{\text{Reference cell laser absorption quantity}}{\text{Reference cell laser received light strength}}\right)}$$

Turbulence analysis of gas concentration

(1) Fourier transform of measured values (t: time→r: eddy scale)

(2) C_g^2 calculation by structure function analysis of gas concentration

$D_{gg}(r)=[G(x+r)-G(x)]^2=C_g^2 \cdot r^{2/3}$

(3) Calculation of dissipation rate ε_g of concentration $\varepsilon_g=C_g^2/f_g(\varepsilon)$

3. Air temperature measurements

Grasping of air temperature

For example:

① Thermocouple

② 2 wavelength laser measurement (2 color method)

③ Absorption spectrum analysis, etc.

Turbulence analysis of air temperature

(1) Fourier transform of measured values (t: time→r: eddy scale)

(2) C_T^2 calculation by structure function analysis of temperature

$D_{TT}(r)=[T(x+r)-T(x)]^2=C_T^2 \cdot r^{2/3}$

(3) Calculation of dissipation rate ε_T of temperature

$\varepsilon_T=C_T^2/f_T(\varepsilon)$

Grasping of influence of latent heat flux by relations of each structure function

(1) Calculation of humidity structure function parameter C_q by relations of each structure function C_n, C_T, C_g

$$Cn^2=\left[\frac{A_T^2}{\bar{T}^2}\cdot C_T^2+\frac{A_Q^2}{\bar{Q}^2}\cdot C_q^2+\frac{A_G^2}{\bar{G}^2}\cdot C_g^2+2\cdot\frac{A_T\cdot A_Q}{\bar{T}\cdot\bar{Q}}\cdot C_T\cdot C_Q+2\cdot\frac{A_T\cdot A_Q}{\bar{T}\cdot\bar{G}}\cdot C_T\cdot C_g+2\cdot\frac{A_Q\cdot A_G}{\bar{Q}\cdot\bar{G}}\cdot C_Q\cdot C_g\right]$$

$\bar{\ }$: Average value of each physical quantity

A : Constant of each physical quantity [∞ f (P, λ)]

P: air pressure λ: measurement laser wavelength

Fig. 17B

(2) Calculation of dissipation rate ε_q of temperature

$$\varepsilon_q = C_q^2 / f_q(\varepsilon)$$

Analysis based on MOS law

① L: Obukhov length: $\frac{z}{L} = \frac{k_v \cdot g \cdot z \cdot T_*}{u_*^2 \cdot T}$

② u_*: Friction velocity$= \overline{(-u^1 \cdot w^1)}^{1/2} = \frac{k_v \cdot z \cdot e}{f_u = (z/L)}$

③ T_*: Friction temperature$= \overline{(w^1 \cdot T^1)} = \frac{k_v \cdot z \cdot e_T}{f_T = (z/L)}$

④ Q_*: Friction specific humidity$= \overline{(w^1 \cdot Q^1)} = \frac{k_v \cdot z \cdot e_q}{f_q = (z/L)}$

⑤ G_*: Friction specific concentration$= \overline{(w^1 \cdot G^1)} = \frac{k_v \cdot z \cdot e_g}{f_g = (z/L)}$

·z: Measuring length
·k_v: von Karman Constant
·g: Gravitational constant

(1) Gas flux: $G = \rho \cdot u_* \cdot G_*$

(2) Momentum flux: $M = \rho \cdot u_*^2$

(3) Sensible heat flux: $H = Cp \cdot \rho \cdot u_* \cdot T_*$

(4) Latent heat flux: $E = L_\theta \cdot \rho \cdot u_* \cdot Q_*$

·ρ: Air density
·Cp: Air constant pressure specific heat
·L_θ: Latent heat